Monocentric urban simulation models: getting closer to fractal properties and landscape representation

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ongoing work with

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Outline

Urban expansion forms/planning

Scattered/leapfrog urban development (sprawl)

- Excessive expansion $->$ market failures (infrastructure costs, open land loss,...)
- Sprawl forms $->$ environmental impacts (emissions, fragment ecological habitats,...)
- Unsatisfactory compactness policy
  - commutes beyond green belts, households deviate because of non-attractive/low acceptability of densification, lack of green space,...
  - pollution exposure may increase (Schindler Caruso CEUS 2014)
  - modest impact on energy and land use consumption (Echenique et al JAPA 2012),
  - ...

Urban expansion forms/planning

More innovative land use policies?

- Any better (if not optimal) morphologies than just compact or growth boundary policies?
- Fractal-based planning ? (Tannier, Frankhauser &co, Cavailhès et al. EPA 2004) allying access to (sub-)centers and to a diversity of open space

Requires deeper microeconomic understanding of the emergence of detailed 2D urban expansion morphologies (and their fractal properties)

Monocentric models and scattered/leapfrog dvlpt

Urban economics: discontinuities arise from

- Anticipations Fujita 82, Turnbull 88, uncertainties Capozza Helsley 90, Bar-Ilan Strange 96, spatial interactions since Beckmann 76
- Equilibrium with mixed ring from interactions Fujita Ogawa 82, Cavailhès Peeters Sekeris Thisse 04 RSUE, Turner JUE 05
- ...but all assume radial symmetry, despite
    - *'satisfactory theory should yield all possible configurations'* Fujita Ogawa
    - sprawl and scatteredness are essentially about 2D forms

2D Spatial explicit models with land-market

- exogeneous fractal form (Cavailhes EPA 04) or green space (Wu Plantinga)
- with endogenous open-space externalities or repelling density effects Irwin Bockstael 02 JEG, Caruso et al 07 RSUE, Caruso et al 15 CEUS

Exogenous theoretical fractal

Cavailhès et al. 2004, EPA (36) 1471-1498

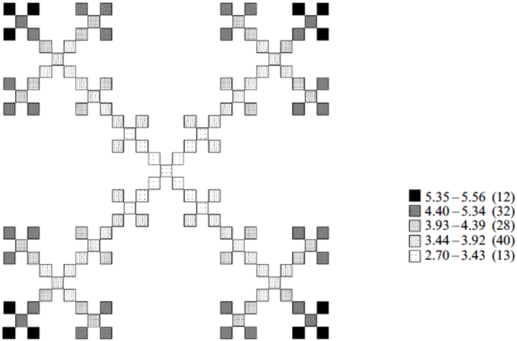


Figure 6. Global accessibility to urban centres and green areas for simulation

Figure: Alonso-Sierpinski rejoinder

Example from SGHOST model family

SGHOST 'Self-Generating Housing Open Space and Transportation'

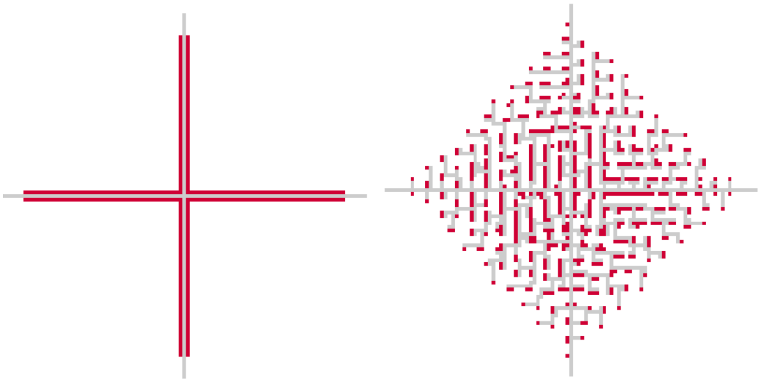
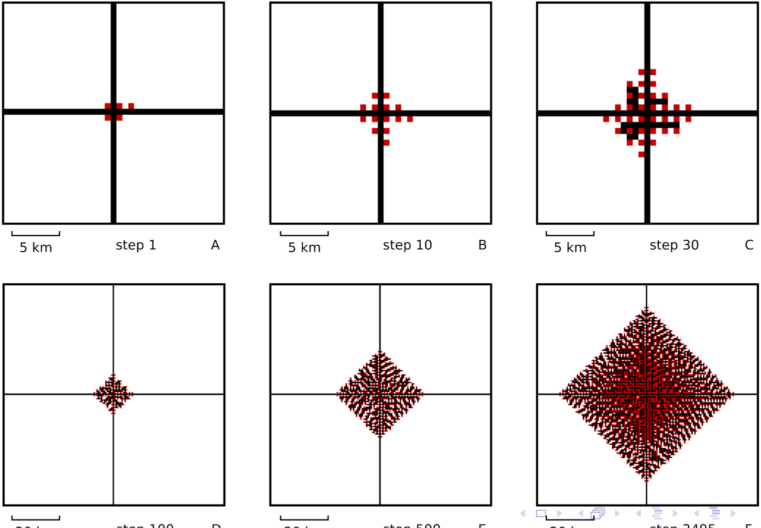


Figure: SGHOST long-run equilibria: Alonso case (left), case with neighbourhood green preference (right)

Example from SGHOST model family

SGHOST calibrated to Brest-Besançon-Dijon land market data



Objectives of this paper (1/3)

Solving 2 'spatial pattern' problems

1. Emerging forms lack 'multiscalarity':
   - too regular green space size and road branching
   - $><$ real cities and observed fractal dimensions
2. Road infrastructure
   - consume lots of land (and cost nothing to households)
   - detours because of lock-ins (houses cannot be destroyed for a road to free up backyard undeveloped land)

Objectives of this paper (2/3)

Solving 2 'behavioural'/microeconomic problems

1. Local interactions occur within a given fixed radius around each house
   - $><$ potential approaches (distance weighting, e.g. Ogawa Fujita, or spatial interaction, or DBM)
   - $><$ green space diversity, not local density solely, matter
2. Dynamic system with free entry (open city) but residents may organize (clubs/authority) to prevent new entry and keep endogenous local amenities and utility at higher level

Objectives of this paper (3/3)

Contribute new geocomputational approaches

1. 'vector local landscape' and accesses adapted trough time $><$ focal interaction (radius-based CA type)
2. 'correct anticipation' of one own's decision: compute landscape at t for all possible decision at $t-1$ before choosing decision at t

The model

Space and agents

- 1 square grid of cells with 1 CBD at (0,0)
- 2 preexisting roads
  - exogenously financed
  - cross at CBD
  - all roads pass in-between cells
- 2 classes of land use:
  - Residential
  - Undeveloped (= Green = Agricultural)
- 4 types agents:
  - Landowners: absentee – arbitrate auctions and pocket rents
  - Households: arrive and locate sequentially
  - Farmers : passive – constant bid rent, opportunity rent R_A
  - Public authority: provides roads, levies tax, stop in-migration if detrimental to aggregate welfare (TDR)

Space and agents

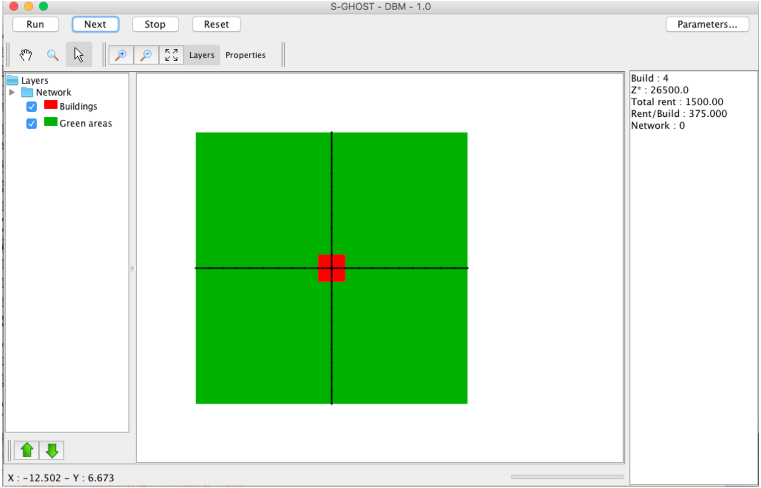


Figure: Prexisting grid, roads and core

Dynamics

Sequential arrival of households

1. Migrant evaluates each undeveloped cell, road network follows (minimized new roads at each t), and landscape patches divide accordingly $->$ Utility computed for each cell given new landscape and transport costs.
2. Migrant picks-up cell where utility is max ($= U^t$)
3. Short-run equilibrium at each t: Rents adapt simultaneously. All households obtain same utility regardless of their location.
4. Authority checks *Total Differential Rent* (TDR=Welfare). If TDR drops: migration stopped. 'Optimum'
5. Long-run equilibrium if not stopped earlier . At t^*: households obtain the utility of the rest of the world, $\overline{U}$. No incentive to migrate $\forall x \; U^{t^*}(x) = \overline{U}$.

Households' decision

Indirect utility (constant lot, no amenities but access costs)

$$u(x) = Z(x) = Y - a_0 \cdot \tau \cdot d(x,0) - \frac{F}{N} - \frac{c \cdot L}{N} - \sum_j b_j \cdot d(x,k) \cdot \tau - R(x)$$

- Commuting costs: freq a_0; unit cost τ; network distance d
- Urban infrastructure costs: fixed (F); and according total road length (L)
- Access to green space k of category j; freq of use: b_j (daily, weekly, rarely)
- R Rent; Y income; Z composite good consumption

Green space: patches and change

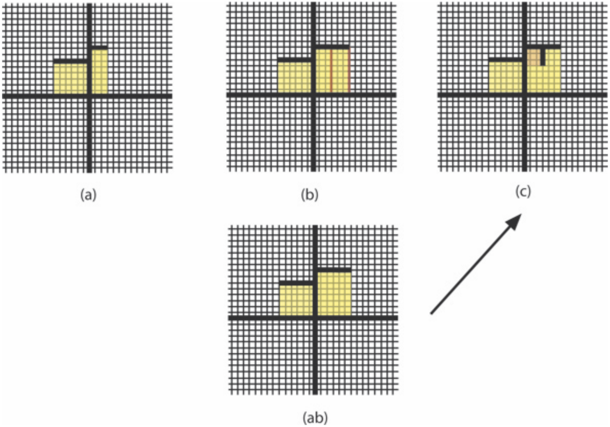


Figure: ∩-shaped, ⊥ to roads, internal limits removed

Green space: attributes of patches

3 criteria

1. Compactness C (area-perimeter ratio)
2. Surface S
3. Access d

Evaluation

- logistics function (no clear cut limits)
- for each type (weekly, daily, rarely), best global evaluation $g_j(k)$ is taken after ranking

Green space: evaluation of patches

$$
\begin{aligned}
g_j(k) &= f_{C(k)} \cdot f_{S(k)} \cdot f_{d(\mathbf{x},k)} \\
&= (1 - \frac{1}{1 + e^{q(C(k) - C_{crit})}}) \\
&\quad \cdot (1 - \frac{1}{1 + e^{q_j(S_j - S(k))}}) \\
&\quad \cdot (1 - \frac{1}{1 + e^{\delta_j(x_j - d(\mathbf{x},k))}})
\end{aligned}
$$

Mathematical analysis strategy

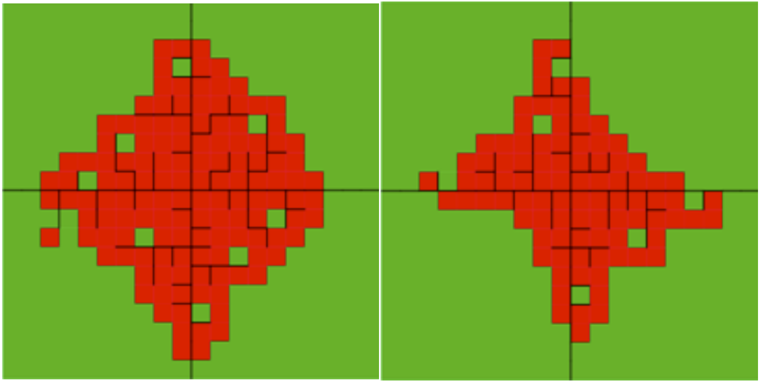
- Mathematical analysis to
  - limit parametric exploration via time consuming simulations
  - retrieve key general properties of the model
- Strategy: find and compares optimum location of newcomer (max Z)
  - with and without total cost of green space access
  - with and without lateral branching (new street)
- incomplete, ongoing

Simulations

- Model implemented in Java (re-programmed from scratch)
- Calibration facilitated since budget constraint only is affected ($><$ preference)
- Calibration made more difficult by green landscape changes
- Preliminary non systematic exploration
    - Standard effects seem well replicated
    - More complex patterns with heterogeneity of green space

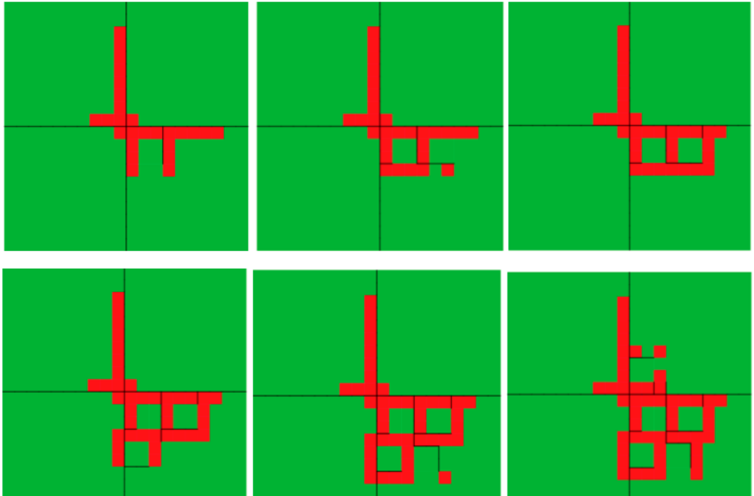
Simulations

low (left) vs high (right) transport cost



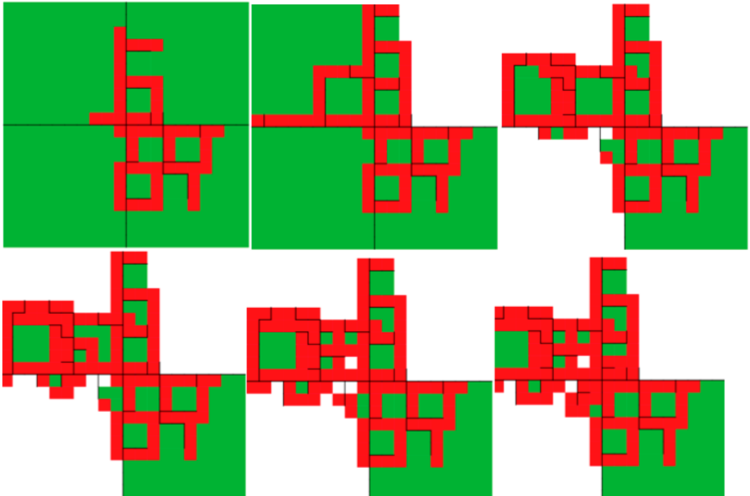
Simulations

dynamics of more surprising patterns



Simulations

dynamics of more surprising patterns (cont'd)



Conclusion so far

- Significant modelling improvement to cope with earlier limitations
- Mixed vector-raster dynamic model and 'anticipation'
- Optimum / Equilibrium in a sequential spatial dynamic context
- Exploration is rather promising: heterogeneous green space while standard effects also replicated
- Still simple model but reaches limit of manual exploration while math analysis can only partially help $->$ many runs still needed to identify phase space and important transition
- Frugality/Complexity in theoretical spatial land market ABM